The SunShot Swerve

Dick Swanson
President Emeritus, SunPower Corporation

We are at a Seemingly Paradoxical Time

- Lots of doom and gloom over excess capacity, depressed prices, and reduced incentives

However

- The market is huge (~$100 billion), growing rapidly, and quickly reaching cost parity

Key Success Metrics for Solar Today

- Technical Feasibility
  - High penetration grid impacts
- Cost and Financial Feasibility
  - Efficiency and materials utilization
  - Manufacturing capital cost and scalability
  - Reliability
- Societal Feasibility
  - Environmental impacts

Why the Swerve is Needed

- We have made remarkable progress. Solar technology is close to becoming a major source of clean energy today.
  - Cost approaching parity with other sources
  - Installed capacity becoming meaningful
- But there remain many cost and technical barriers before the dream is fully realized.
  - We need a push…a swerve.

The Far-Reaching Aspects of SunShot

- Set very aggressive goals for module and BOS costs that have spurred innovation at all companies.
- Recognized importance of reducing BOS and soft costs.
- Recognized the importance of understanding grid impacts at high penetration.

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  - Distribution Planning and Operations
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Call for Papers: IRED

Plug-and-Play Funding Available

Forecasting Accuracy Funding Opportunity

Paper Addresses Interconnection Screens

FEATURE ARTICLE

Updating Distribution Interconnection Screening Procedures: From One-Size-Fits-All to Custom-Tailored Strategies

May 23, 2012

Given the rapidly expanding solar market, the authors of a recent report examined the technical basis for the current 15% penetration screen. Their findings helped start a

ASK AN EXPERT

Q. Is the DEW model a 3rd party software program and how was this conversion made?

A. DEW, or Distributed Engineering Workstation, is a 3rd party product available from Electrical Distribution Design. A custom converter (written in

NEWS

NREL Develops More Precise Look at Cradle-to-Grave Greenhouse Gas Emissions for Energy Technologies
May 4, 2012 | **NREL News**

Energy Department Announces Funding to Develop "Plug-and-Play" Solar Energy Systems for Homeowners
April 24, 2012 | **U.S. Department of Energy - Press Releases**

More News

EVENTS

SunShot Grand Challenge: Summit and Technology Forum
June 13, 2012 - June 14, 2012

More Events

FEATURES

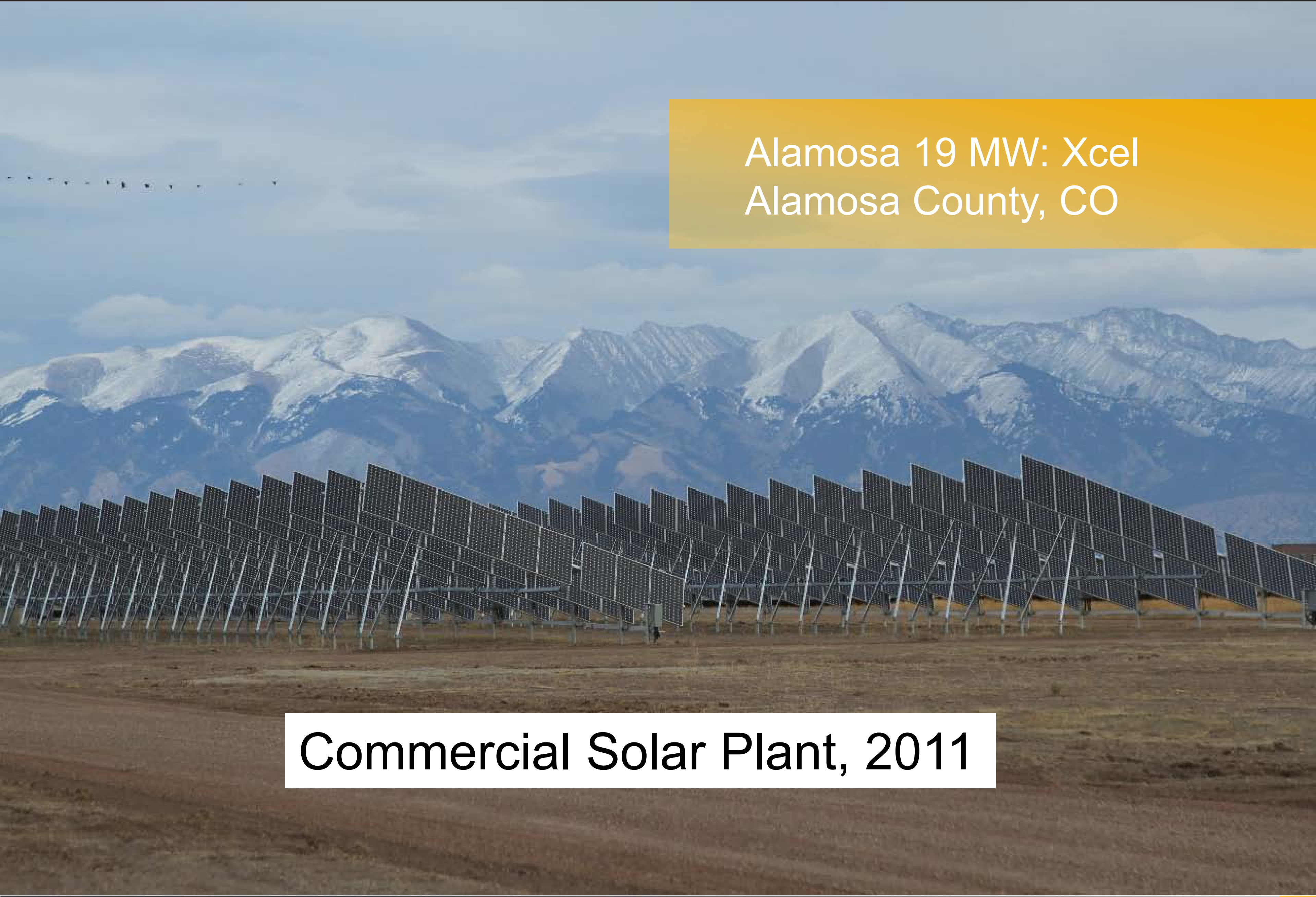
Distributed Wind and Solar Interconnection Workshop
February 2012

Get the latest on High Penetration Solar Updates

https://solarhighpen.energy.gov/

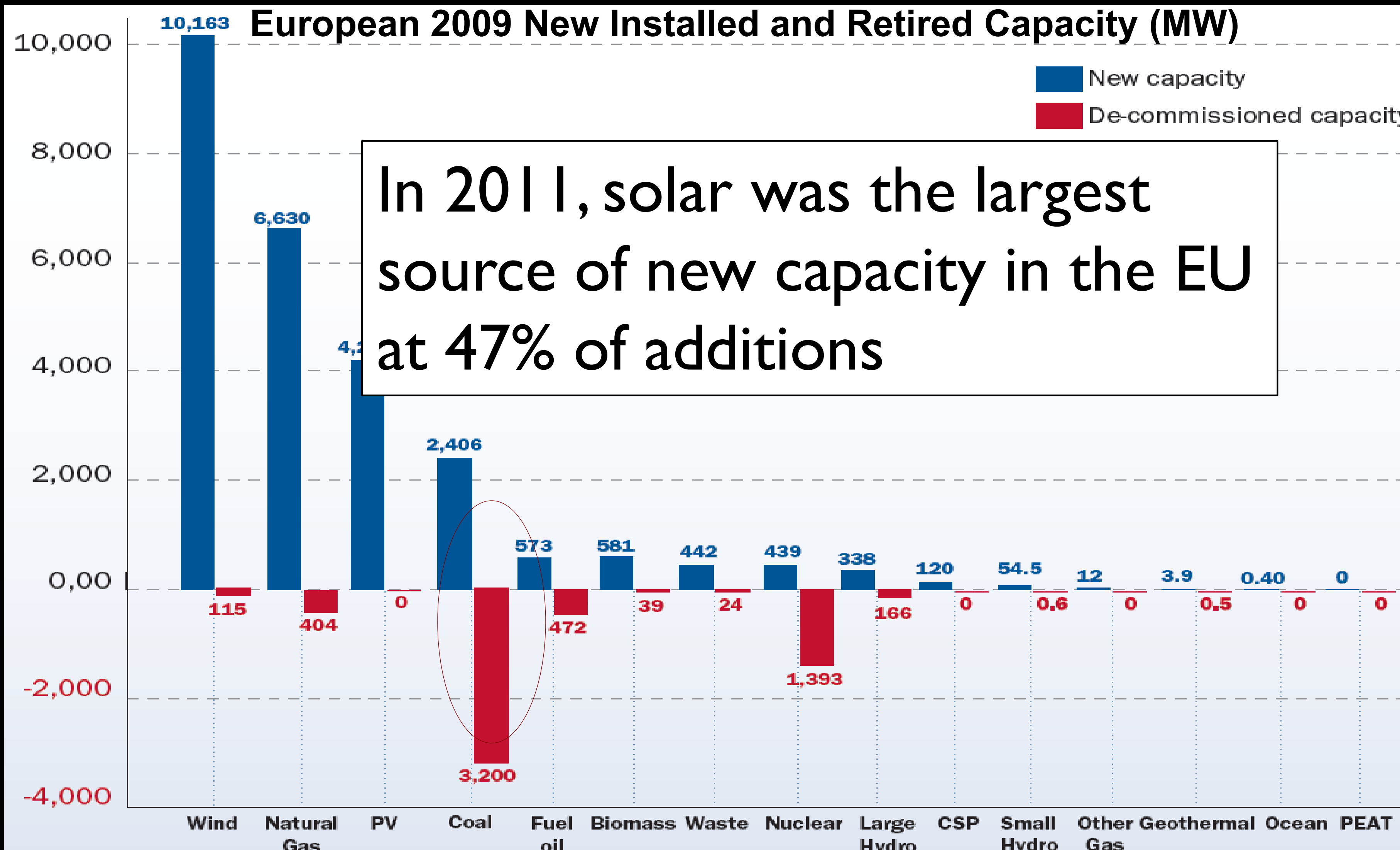
Commercial Solar Cell, ca. 1960
Hoffman Electronics

Alamosa 19 MW: Xcel
Alamosa County, CO



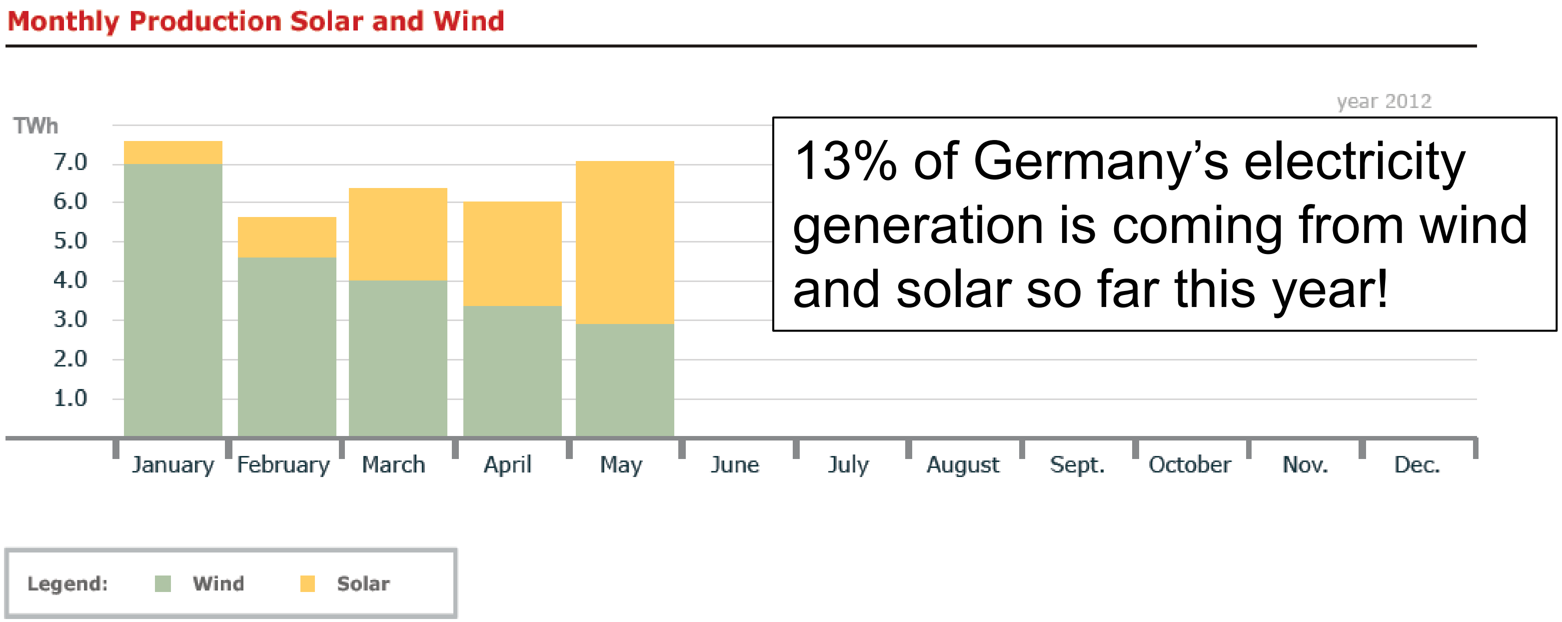
Commercial Solar Plant, 2011

4.2 GW PV in 2009…10+ GW in 2010



In 2011, solar was the largest source of new capacity in the EU at 47% of additions

Monthly Electricity Production of PV and Wind in Germany 2012



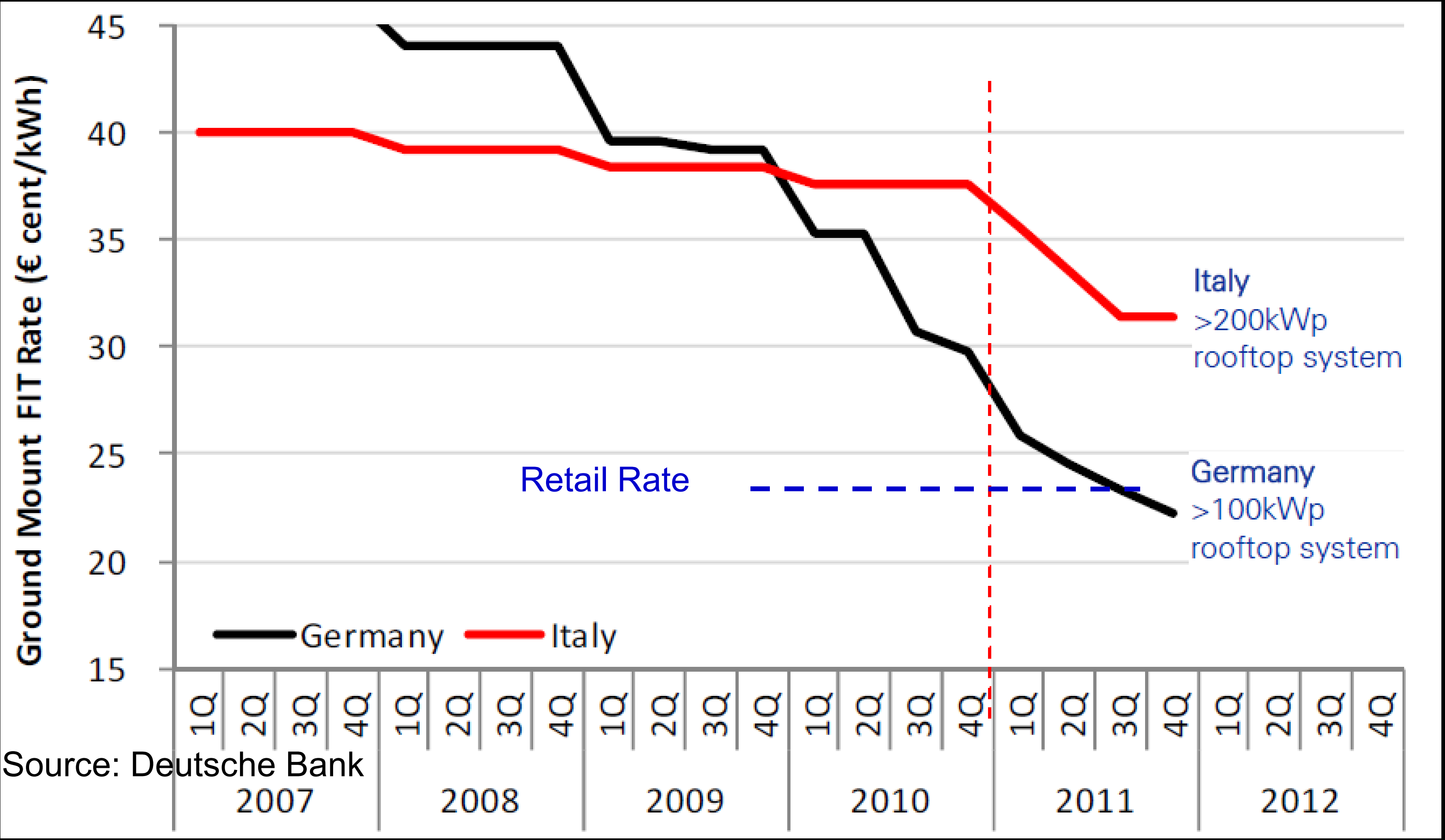
- The maximal sum of PV and wind production was 7,6 TWh in January 2012
- The minimal sum was 5,6 TWh in February 2012
- The total electricity need of Germany is about 600 TWh/yr

Graph: B. Burger, Fraunhofer ISE; http://www.ise.fraunhofer.de/en/news Data: EEX Transparency Platform

From Prof. Eicke Weber's Plenary Talk at PVSC-38

Fraunhofer ISE

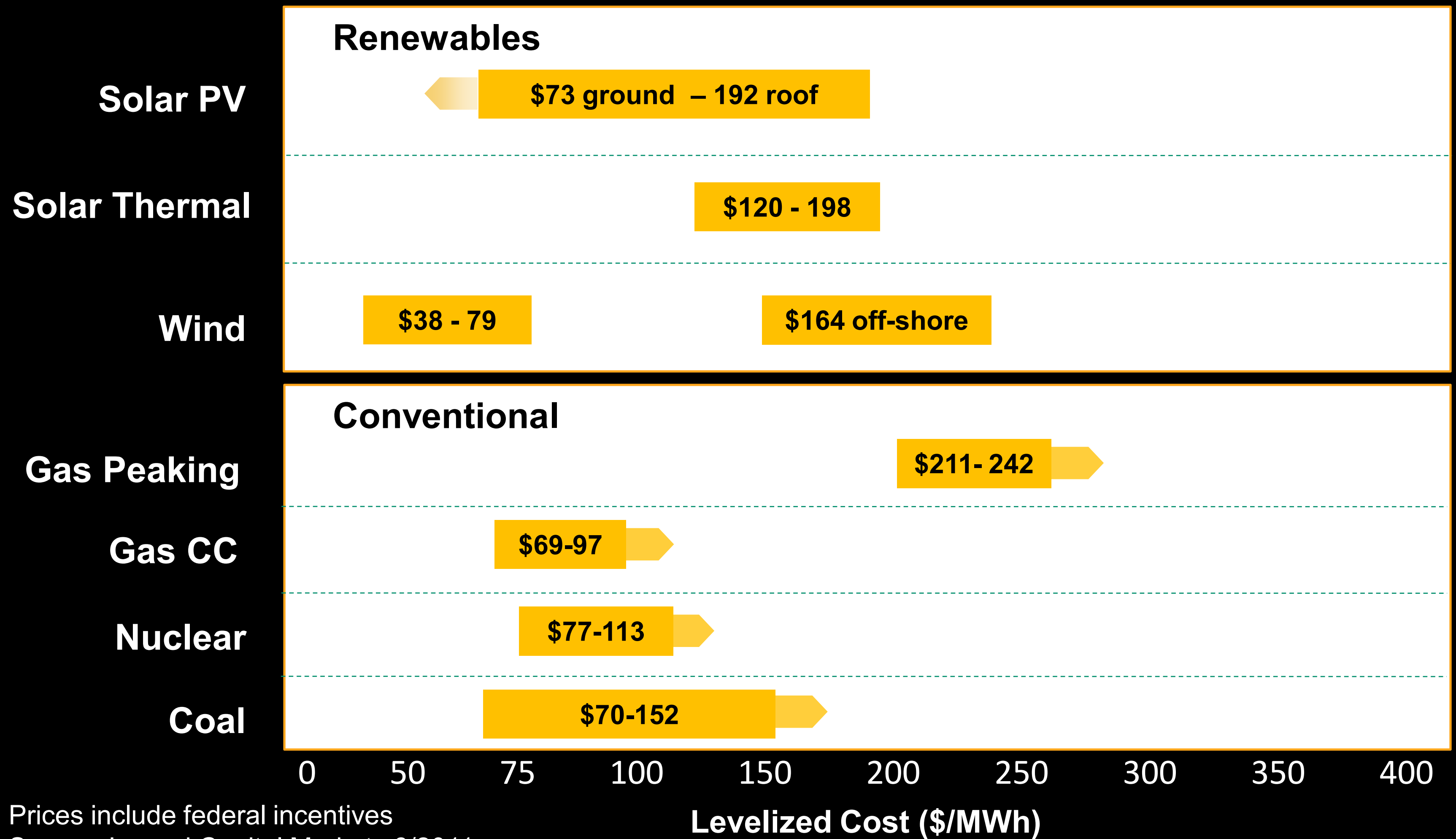
German Feed-in Tariff is Less Than Retail in 2012!



Source: Deutsche Bank

PV Power Plants are Cost Competitive Today

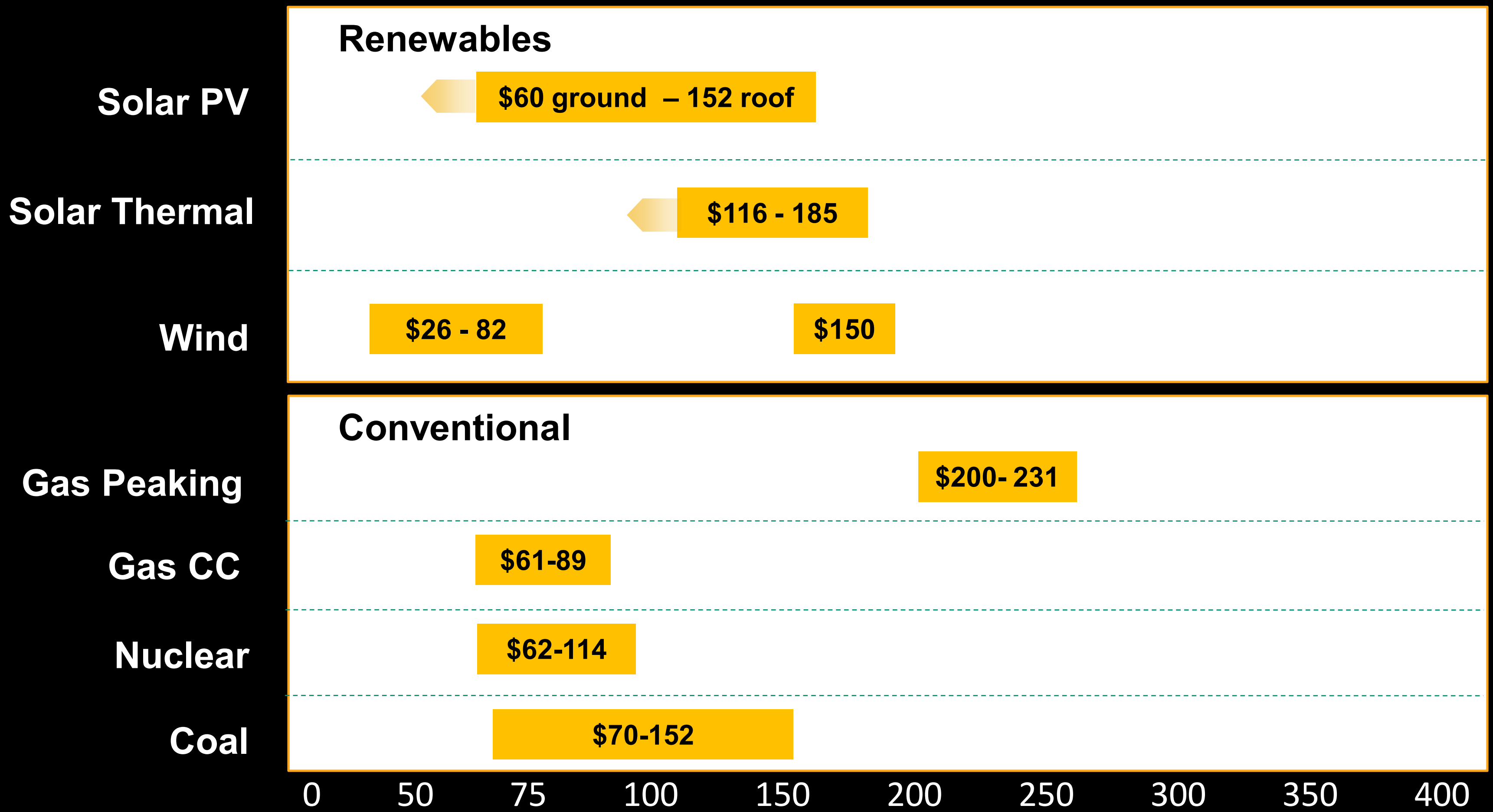
2012 LCOE by Resource $/MWh: 2010 USD



Prices include federal incentives
Source: Lazard Capital Markets 6/2011

Solar PV Power Plants are Cost Competitive

2015 LCOE by Resource $/MWh: 2012 USD



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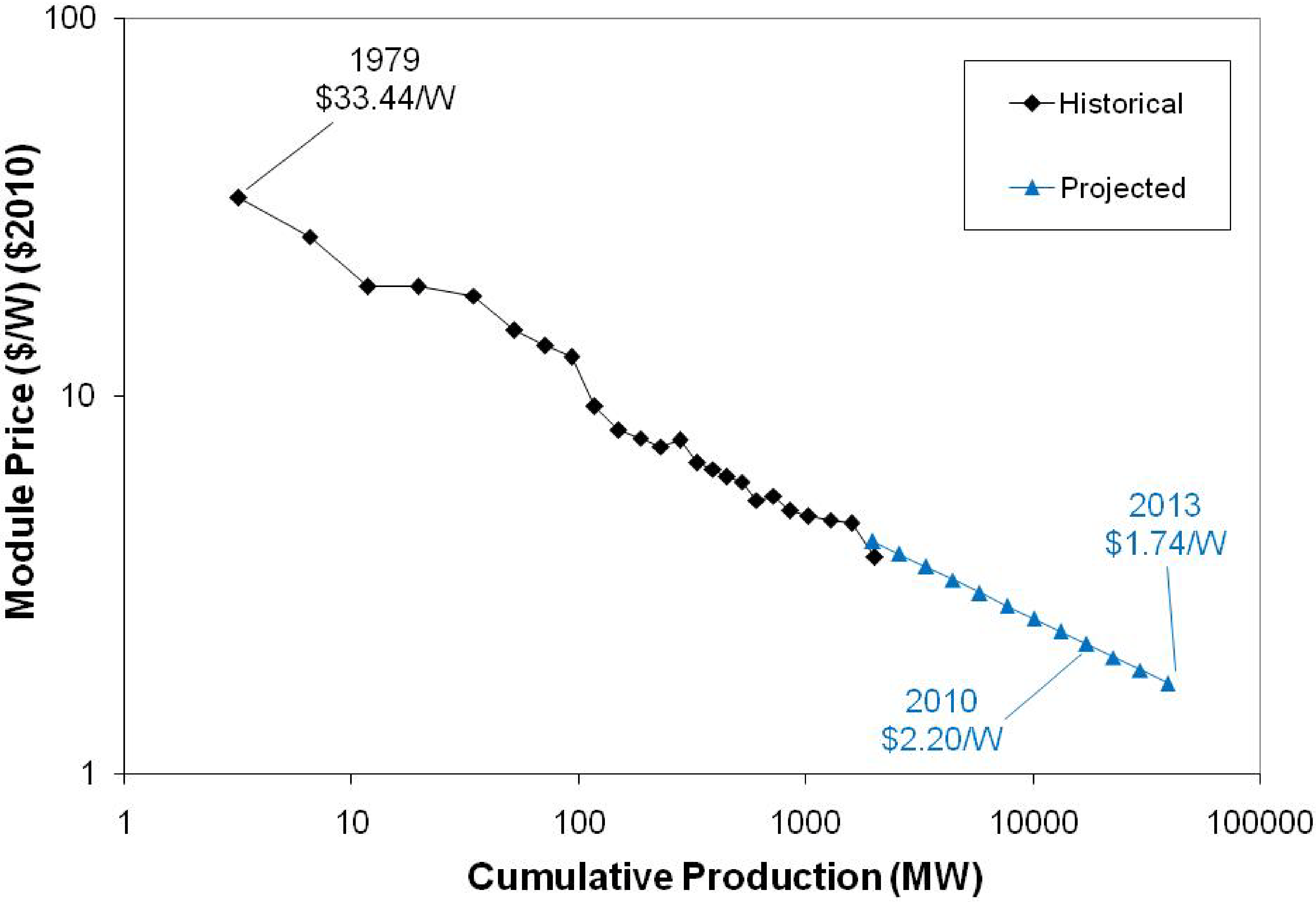
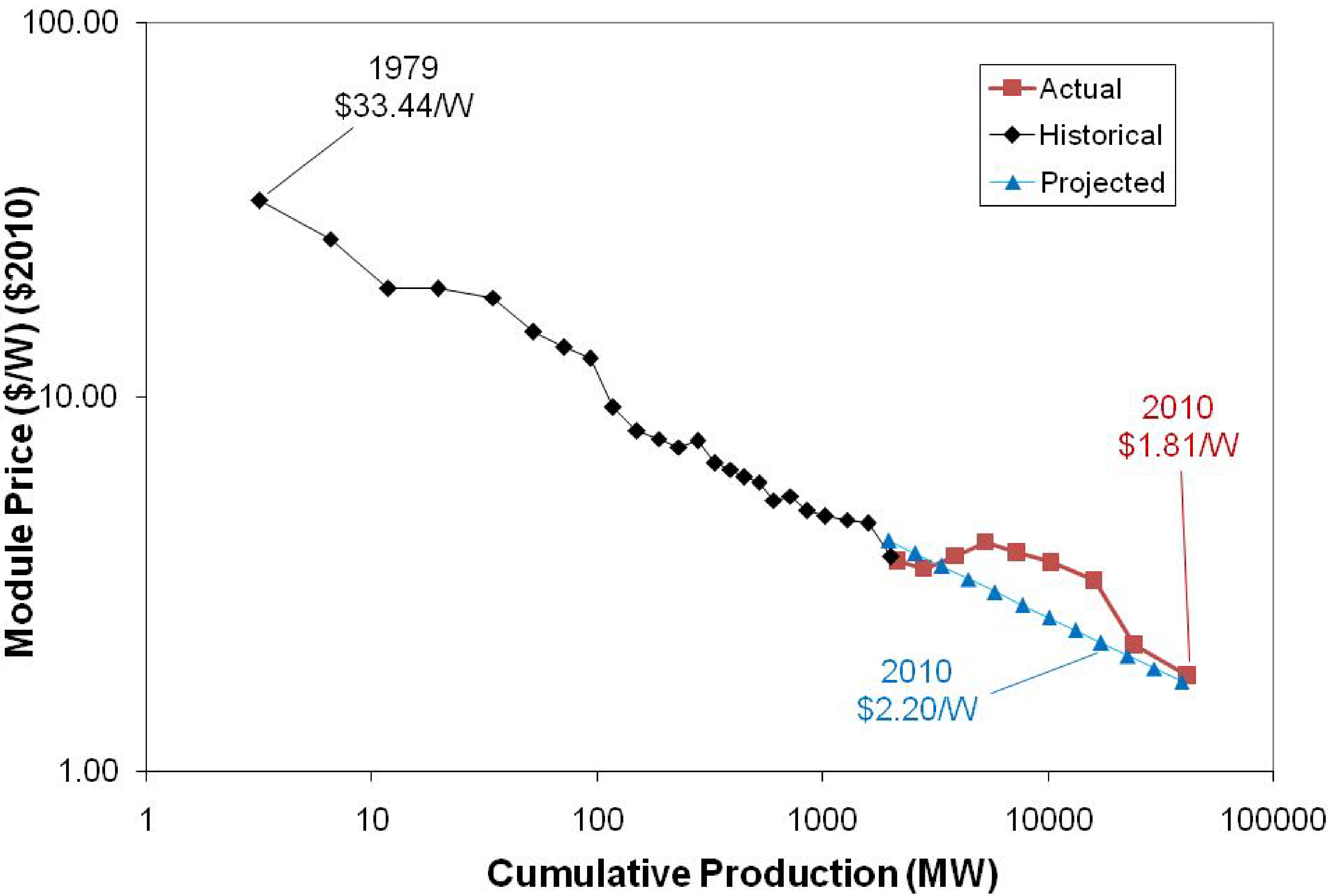
Source: Lazard Capital Markets 6/2012

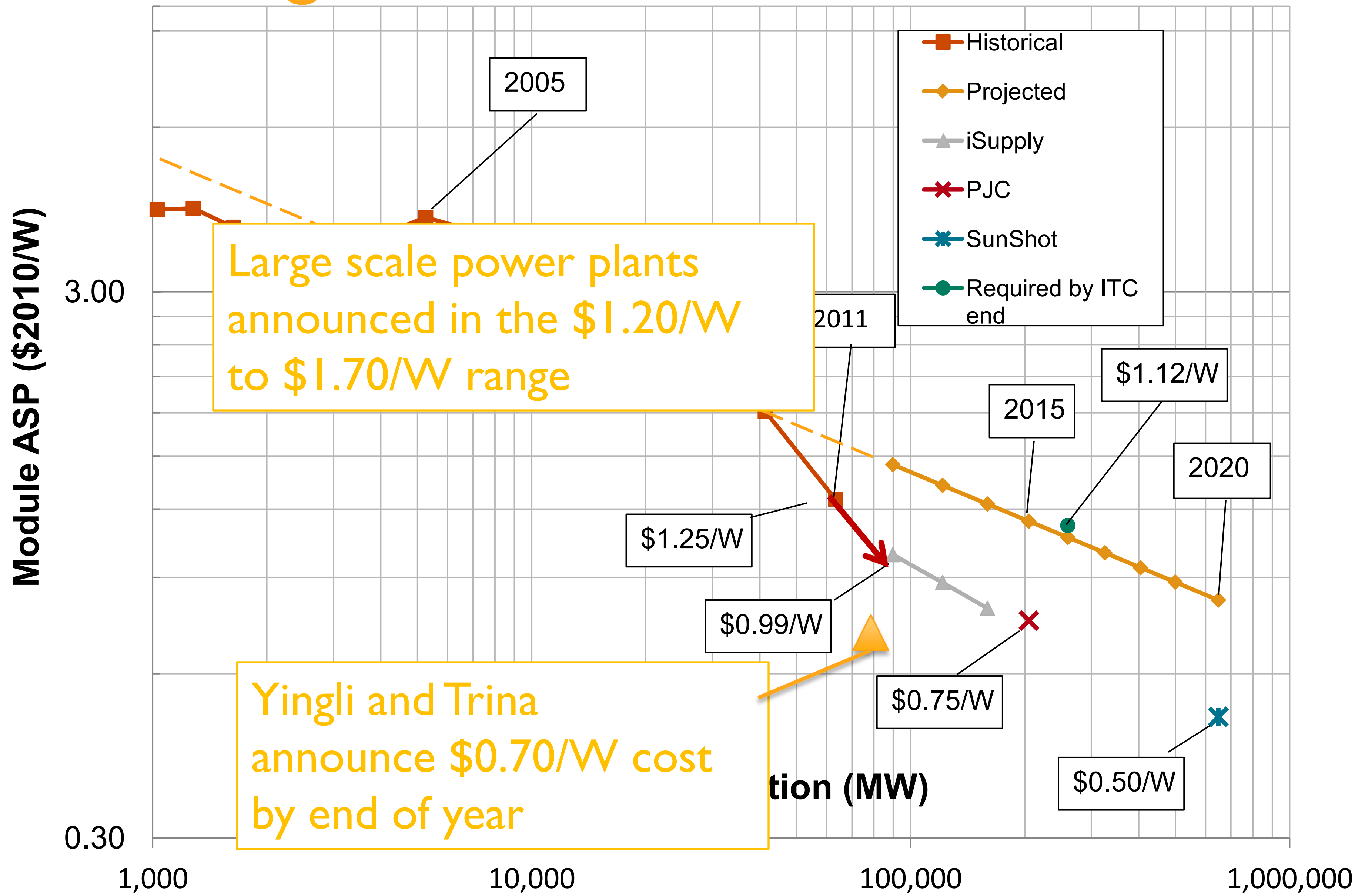
Historical PV Learning Curve ($2010)



Comparison to Actual



Zooming in on Recent Times



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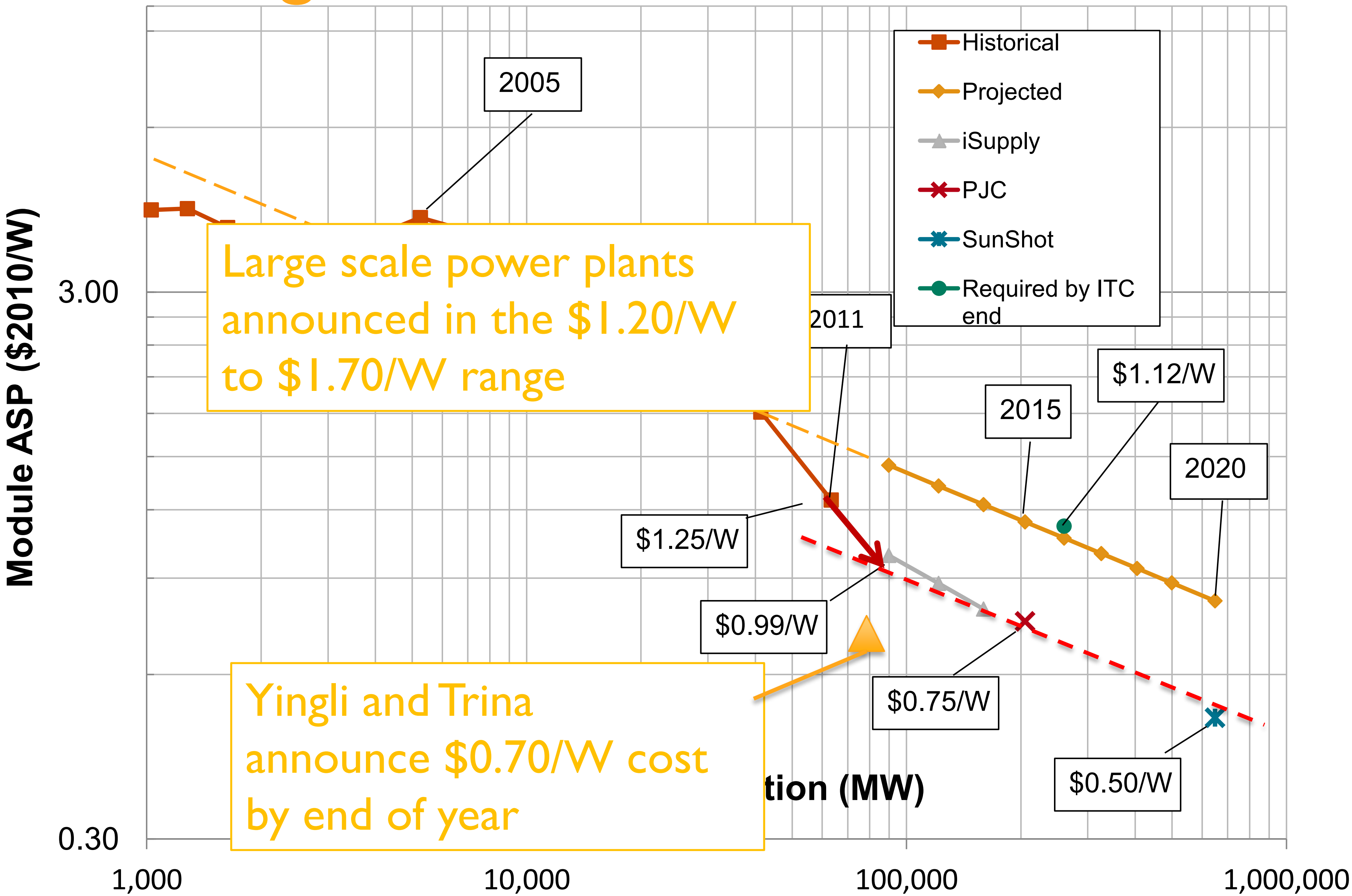
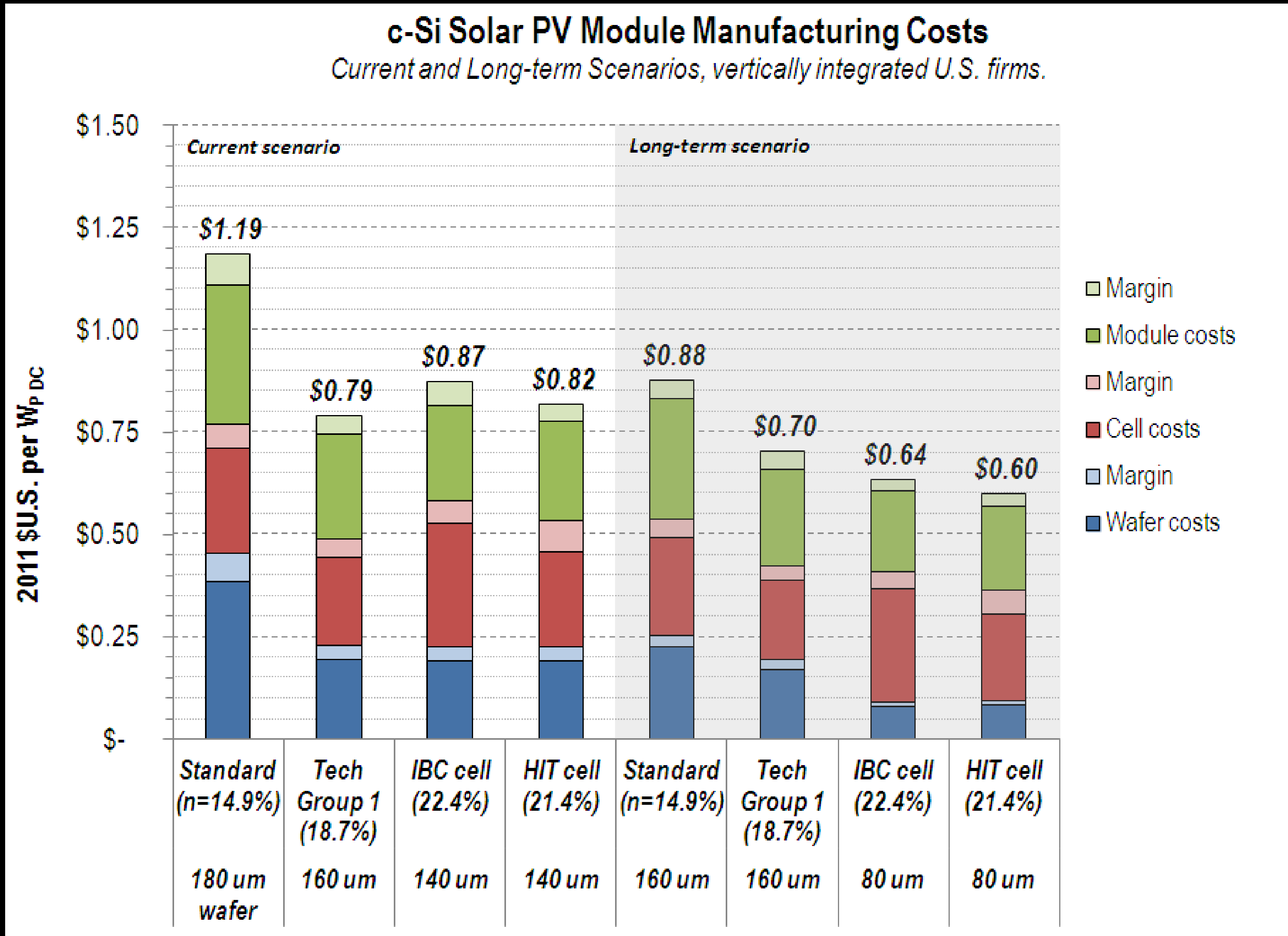
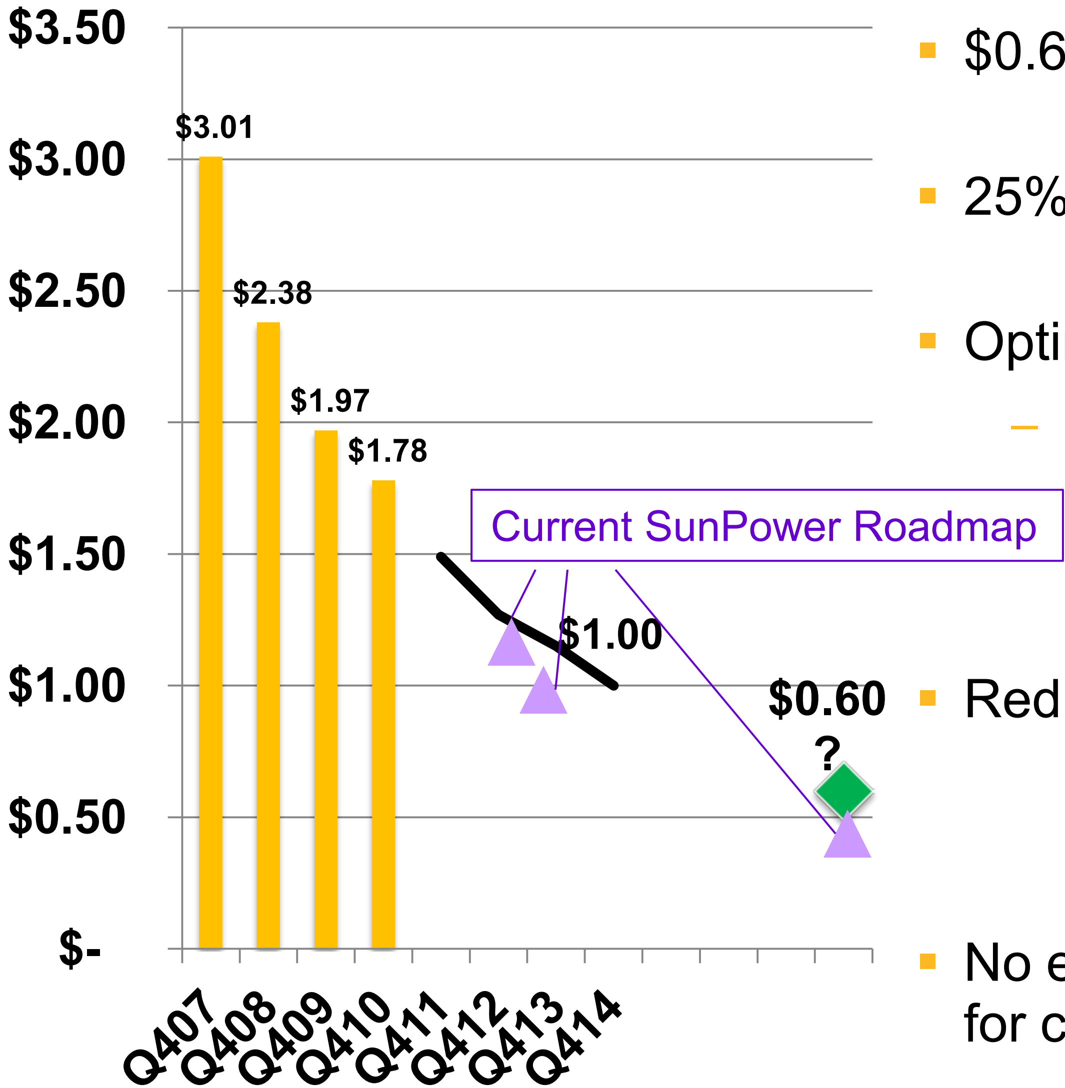


NREL Si Roadmap *in preparation* (Goodrich, A. et al.)



Technology Development Central to Cost Roadmap



- $0.6/W c-Si Module is conceivable
- 25% cell performance practical
- Optimized process sequence
  - Back-contact process is immature (< 8 yrs old)
    - New process-steps and materials
- Reduced silicon usage
  - Ultra-thin wafers (<100 um), reduced Kerf or Kerfless
- No end in sight for learning curve for c-Si back contact solar cells

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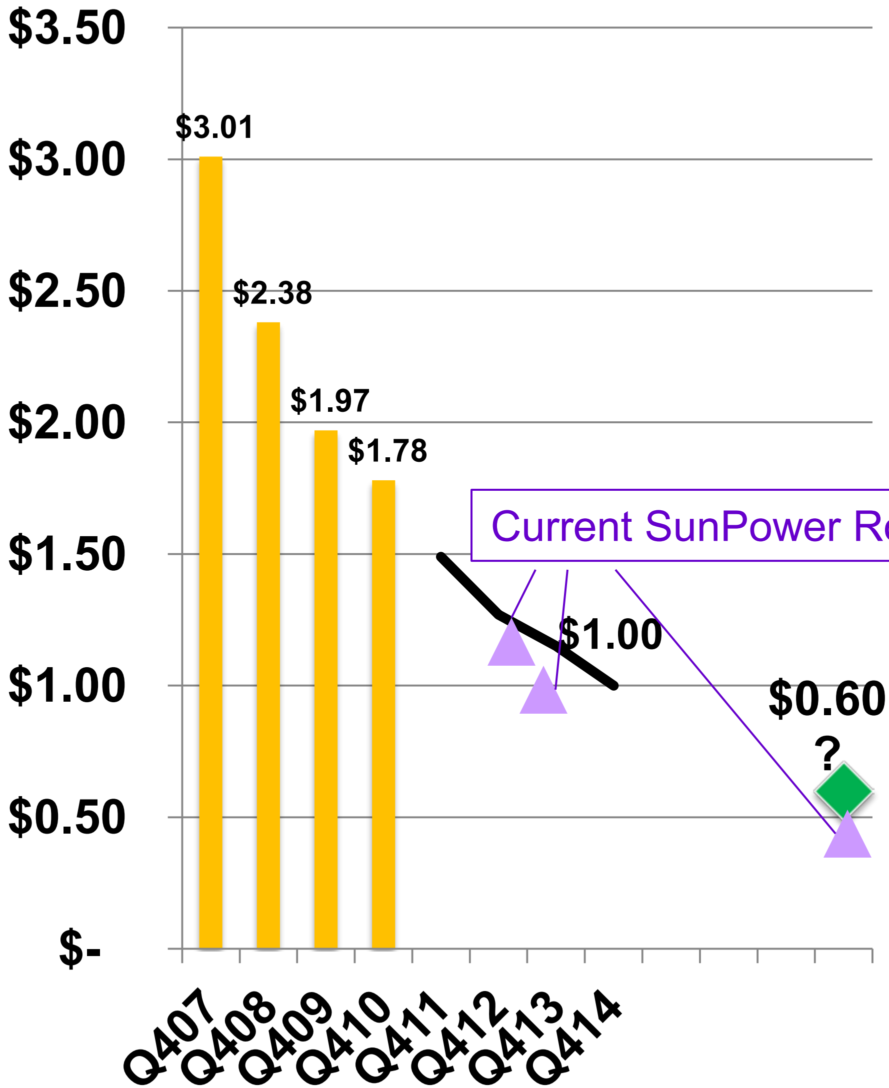

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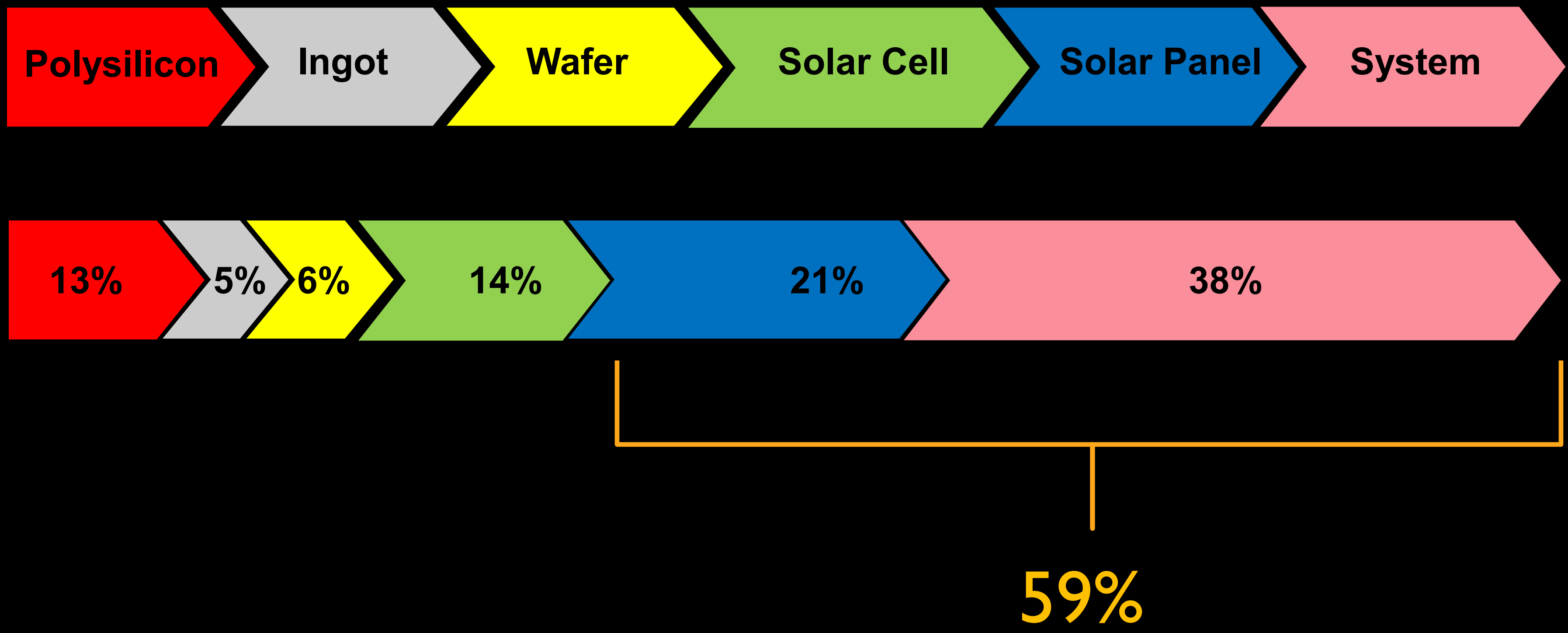
THE IMPORTANCE OF EFFICIENCY

c-Si Value Chain:



Value of Efficiency

- Lowers area-related costs

- Reduced materials costs
  - Less module and system area
- Reduces installation costs
- Reduces shipping costs (module, BOS)

T5 Shipping Pallet

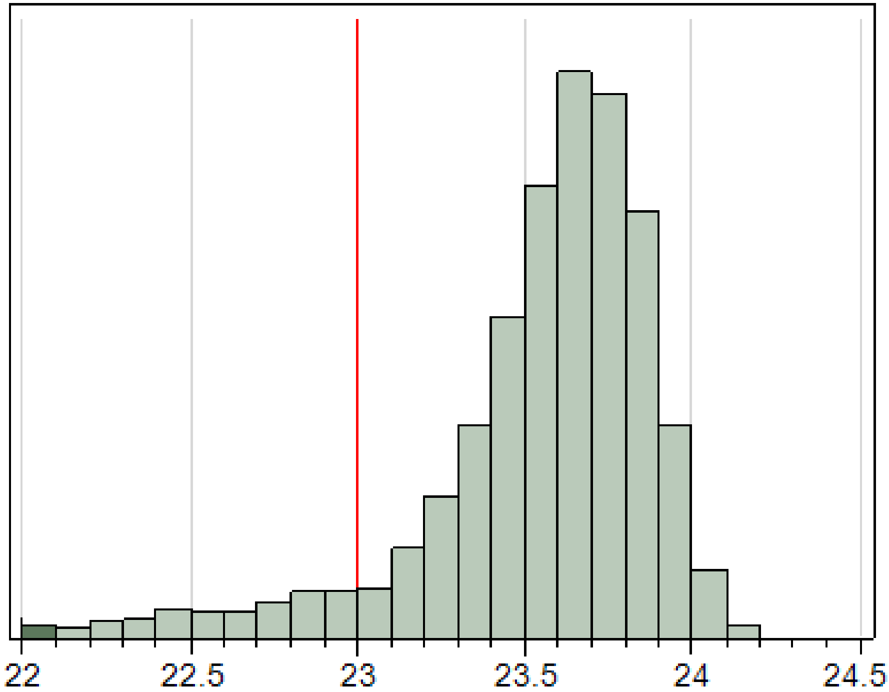
T5 Rapid Installation

- Lowers $/W projects costs

- For area-constrained projects, it allows more Watts for the project
  - **<u>Reduces $/W Fixed Costs</u>**: Distribute sales, design, permitting, etc.) across more watts
  - **<u>Increases Customer NPV</u>**: Larger system power provides higher project NPV even beyond the $/W savings
- For non-area-constrained, it can still give lower fixed costs by allowing optimum selection of mounting location and reduced site preparation

- Increases financial benefit of tracking

Gen 3 Production Data



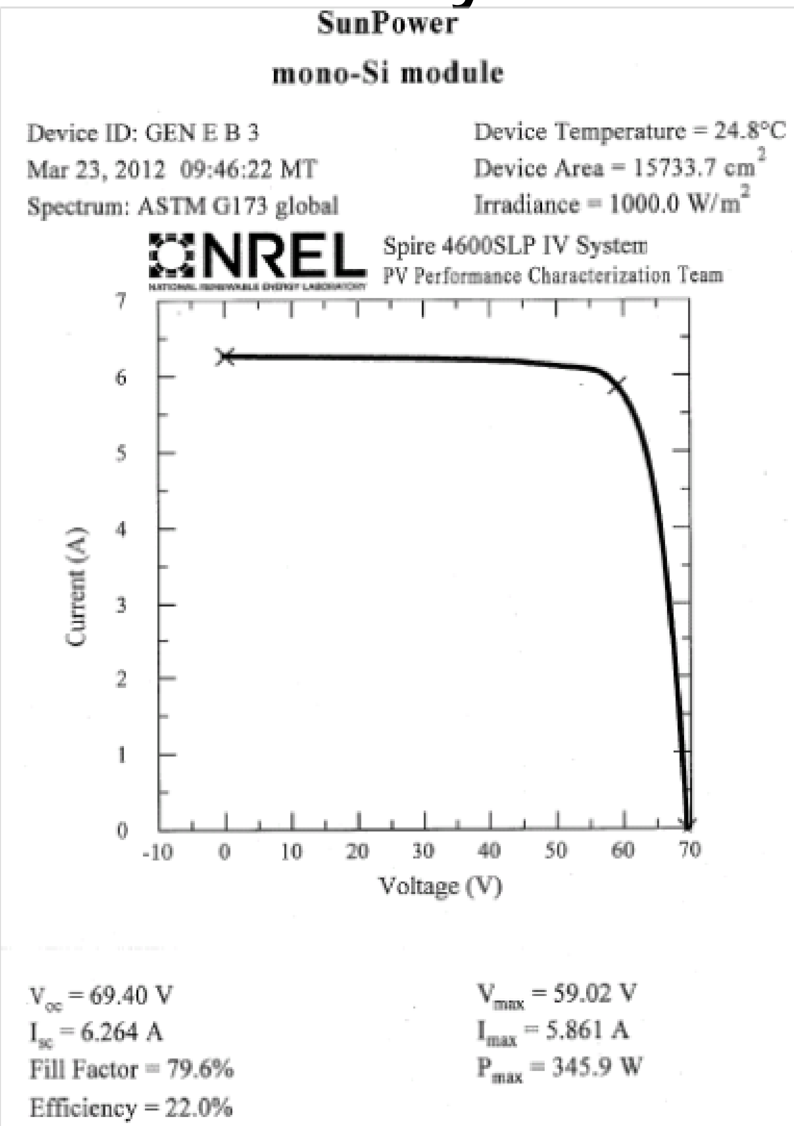
Electrical parameters	Median value
Voc (volts)	0.727
Jsc (mA/cm2)	40.0
Fill factor	81.2 %
Efficiency	23.6 %

- Efficiency distribution from recent production run
- 23.6 % efficiency median, peak cells over 24 %

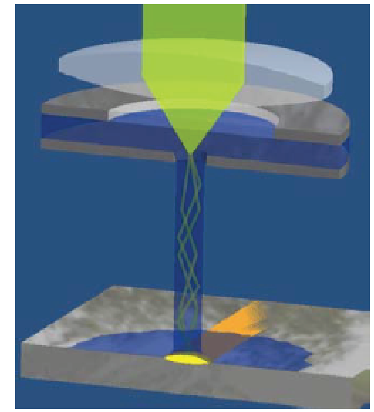
>21 % Total Area Module Efficiency

- **96 cell module measured at NREL 345.9 watts**
- **1.63 m^2 including frame**
- ***21.2 % total area efficiency***
- **Module manufactured when cell efficiency median was 23.2 %**
- **Expected yield to > 21 % module efficiency is high**

Area (m2)	Power (W)	Voc (V)	Isc (A)	FF (%)
1.63	345.9	69.4	6.264	79.6

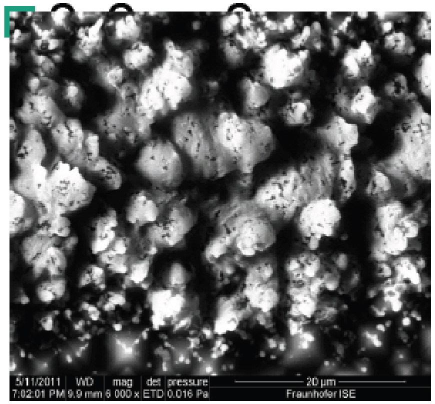


Selective Emitters + Advanced Metallisation
High-efficiency Solar Cells



Properties:

- Dielectric rear passivation
- Lowly doped emitter



		J_{SC} [mA/cm²]	V_{OC} [mV]	FF [%]	pFF [%]	η [%]
120 Ω/sq	Best cell	38,2	673	81,3	84,2	20,9*
	Ø 1 4 cells	37,5	671	81,6	83,8	20,4

*independently confirmed by CalLab PVCells at Fraunhofer ISE

Fraunhofer ISE

Future Trends in Crystalline Silicon

- Evolutionary
  - Thinner wafers
  - Cu metal
  - Diamond wire sawing
  - Improved efficiency
  - Ink jet patterning
  - New module approaches
- Revolutionary
  - Kerfless wafers
  - Heterojunctions and IBC
  - Cell processing at the module level

Innovation Issues Today in PV Modules

- Scale advantage very large for module makers (c-Si)
- Costs continue to decrease relentlessly
  - The moving target issue
- Efficiency of c-Si continues to increase
  - More moving target, > 20% cells will be the norm soon
- Requires massive manufacturing investment to make a meaningful contribution
  - Large risk for unproven technology
  - 20% global electricity production→5,000 sq. mi. of PV modules
- Product must last outdoors for 25 years
  - Hard to prove without years of field experience

All Viable Solar Technologies Now Must Have a Credible Path to $1/W*

- Crystalline silicon
- Thin films (a-Si, CdTe, CIGS, CZTS)
- CPV
- CSP
- New technologies (OPV, dye-sensitized, 3rd generation…)

Crystalline Si must be considered a front runner in this quest.

*Constant 2010 dollars, adjusted for tracking, energy/W of modules, direct normal resource (for CPV and CSP), and reliability vs. baseline assumptions.

WE LOOK FORWARD TO THE CONTINUED CONTRIBUTION OF THE SUNSHOT PROGRAM TOWARD THE GOAL OF EXTREMELY LARGE-SCALE ENERGY GENERATION FROM COST-EFFECTIVE SOLAR

THANK YOU